MAILED

MAY 15 1932

To Library L. M. A. L.

MAY 18 1932 [redacted]

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Note 418

COMPRESSION-IGNITION ENGINE TESTS OF SEVERAL FUELS

By J. A. Spanogle
Langley Memorial Aeronautical Laboratory

FILE COPY
To be returned to
the files of the Langley
Memorial Aeronautical
Laboratory.

Washington
May, 1932

NASA Technical Library
3 1176 01425 5765

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 418

COMPRESSION-IGNITION ENGINE TESTS OF SEVERAL FUELS

By J. A. Spanogle

SUMMARY

The tests reported in this paper were made to devise simple engine tests ~~which~~ that would rate fuels as to their comparative value and their suitability for the operating conditions of the individual engine on which the tests are made. Three commercial fuels were used in two test engines having combustion chambers with and without effective air flow. Strictly comparative performance tests gave almost identical results for the three fuels. Analysis of indicator cards allowed a differentiation between fuels on a basis of rates of combustion. The same comparative ratings were obtained by determining the consistent operating range of injection advance angle for the three fuels. The difference in fuels is more pronounced in a quiescent combustion chamber than in one with high-velocity air flow. A fuel is considered suitable for the operating conditions of an engine with a quiescent combustion chamber if it permits the injection of the fuel to be advanced beyond the optimum without exceeding allowable knock or allowable maximum cylinder pressures.

INTRODUCTION

Much interest has been shown in the development of fuels for internal-combustion engines and improvement in engine performance has been a direct result of the improvement of fuels. The evaluation of the results of efforts to improve fuels requires that there be a suitable standard set up for the comparison of the operating characteristics of the different fuels involved. The standard known as octane number has been adopted for fuels for spark-ignition engines and is apparently quite satisfactory. In the rating of fuels for compression-ignition engines much work has been done without arriving at an adequate standard although arbitrary ratings have been developed ~~which~~ that give a good com-

parative ranking to a series of fuels. The complex interrelation of the variables affecting combustion in a compression-ignition, fuel-injection engine makes it difficult to set up a satisfactory standard of engine characteristics and test conditions without which it will be much more difficult to erect the standard for the fuel.

The characteristic of a fuel that is conceded to be of utmost importance in determining its usefulness is its ignitibility. The usual method of evaluating this ignitibility is by measurement of the ignition lag. For these tests ignition lag is considered to be the interval between the start of the injection of fuel and the point at which the pressure in the cylinder becomes greater than the compression (or expansion) pressure would be if no ignition occurred. This definition of ignition lag is not dependent upon the experimenter's conception of what constitutes ignition but is considerably dependent upon the apparatus used for establishing the end points, especially the indicating apparatus with which the pressure-time or pressure-volume cards are taken.

NO H.C.G.

The engine tests reported herein were started with the idea of developing a method of rating fuels on a performance basis but it was soon realized that the fuels used for the tests were included within a small part of the range of possible fuels for fuel-injection engines and that no great difference in performance could be expected when engine tests were made under strictly comparable operating conditions. It was, therefore, decided to try to establish tests which would give a satisfactory differentiation between several fuels and which would give some indication of the operating conditions under which a particular fuel might be used in an individual engine.

These tests were made in the power-plants laboratory of the National Advisory Committee for Aeronautics during December, 1931 and January, 1932.

FUELS AND APPARATUS

The commercial fuels used in these tests will be referred to as fuels 1, 2, and 3. Fuel 1 was bought in the open market by competitive bids based on U. S. Government specifications. Fuels 2 and 3 were furnished by another

refiner. Fuel 2 is a recently developed product especially recommended for use in high-speed, compression-ignition, fuel-injection engines. Fuel 3 is the product that has been distributed by this refiner for a number of years for use in the smaller Diesel engines.

The atmospheric distillation curves of the three fuels are shown in Figure 1. The high initial distillation range of fuel 2 should be noted.

The tests were run on two different single-cylinder test engines, one of which had a precombustion chamber with a high velocity of air flow, the other had a vertical disk form of combustion chamber in which there was no effective air flow. Consequently the tests included the two extremes of air flow in combustion chambers. The test conditions were standard throughout except for the variables noted, although less than the customary time was used for precise adjustment of temperatures and other engine-operating conditions, because both the time allotted to the tests and the fuel available were limited. The compression ratios of the engines were adjusted so that the compression pressures were the same.

The start of the injection of the fuel was determined by observing simultaneously the spray and the scale on the flywheel of the engine by means of a Stroborama. This observation was made at atmospheric pressure but as no difference in timing has been found with these injection systems between the start of the spray in the atmosphere and in a pressure chamber it is assumed that the start would be the same in the engine.

Indicator cards were taken with a Farnboro indicator. From these indicator cards the breakaway of the pressure line was determined both during the analysis for rates of combustion and by visual inspection.

Full-load fuel quantity is the calculated quantity of fuel necessary for combustion with the amount of air inducted per stroke. This quantity was considered to be the same for all fuels in these tests. The variation in chemical composition and the difference in inducted air quantity was considered insufficient to affect the data. Also in calculating percentages of heat dissipation all fuels were considered to have the same B.t.u. content.

Engine knock intensities were determined entirely by ear in all tests by the same operator for either engine. The incidence of missing was determined by retarding the injection slowly enough for the engine temperatures to become stabilized. If the retarding is done too quickly the difference in temperature of the combustion chamber walls will have an effect on the miss determination.

TESTS AND TEST RESULTS

The comparative performance tests included variable-fuel-quantity runs on both test engines. In addition to the usual performance data at full-load fuel quantity and 1,500 r.p.m., indicator cards, heat dissipation data, and exhaust gas samples were taken. Starting, idling, and acceleration were noted during the tests, but no special tests were made to differentiate between the fuels. The allowable knock-to-miss range of injection advance angle was determined on both engines.

Variable-speed tests were run with all three fuels only on the test unit with the quiescent combustion chamber. The noncomparative tests were run on the same test unit and included engine performance tests with variable-injection advance angle and both constant b.m.e.p. and constant fuel quantity.

The starting, idling, and acceleration characteristics of all three fuels were nearly the same on both test units except that acceleration was slightly smoother with fuel 2; fuel 3 required a larger fuel quantity and earlier injection for starting in the combustion chamber with air flow.

The performance curves of the variable-fuel-quantity runs with the combustion chamber with air flow were so nearly identical that no differentiation was possible. An analysis of the indicator cards showed that the ignition lag was the same for all fuels but that the maximum cylinder pressure and the maximum rate of combustion were least for fuel 2 and only slightly greater for fuels 3 and 1. Exhaust-gas analysis indicated that fuel 2 utilized about 2 per cent more of the available air than did the other fuels. Heat-dissipation data for all three fuels were the same within experimental error.

The only marked difference in the three fuels when used in the combustion chamber with air flow was in the range of injection advance angle over which the fuel would allow the engine to operate steadily and without excessive knock. The range was 4° for fuel 1, 5° for fuel 3, and 8° for fuel 2.

The variable-speed runs on the test unit with the quiescent combustion chamber were made at full-load fuel quantity and were obviously not suited for comparative tests on account of the variety of injection advance angles required. As this laboratory is primarily interested in engines operating at high speeds, it was considered sufficient to note that there is no contrast between the fuels at 1,250, 1,500, and 1,750 r.p.m.

The variable-fuel-quantity performance data from the engine with the quiescent combustion chamber were similar to those of the combustion chamber with air flow in that the curves were almost identical on a comparative basis, i.e., with the same injection advance angle. From a comparison of the data at full-load fuel quantity the heat dissipation was the same for all fuels and the exhaust-gas analysis indicated that fuel 3 was utilizing about 3 per cent less air than the other fuels. The miss-to-knock range was about 16° for fuels 1 and 3 whereas that of fuel 2 was more than 30°.

The most distinct differentiation between the three fuels was obtained by analysis of the indicator cards from these full-load fuel tests. Figure 2 shows the rates of combustion and the first part of the total-fuel-burned curves as determined by the engine-analysis section. With the same injection advance angle (8° B.T.C.) both fuels 1 and 3 start burning at top center while fuel 2 gets started at 2° B.T.C. and therefore has only three-quarters of the ignition lag of the other fuels. With this shorter ignition lag fuel 2 started burning at a slightly faster rate but reached its maximum quickly; the other fuels started their burning both later and more slowly and reached higher maximum rates of burning.

Indicator cards were taken with the injection starting at top center so that the compression line under load would be determined more accurately than would be possible from a motoring card. The peaks of these cards are reproduced in Figure 3 and are included because they show very clearly

how the ignition characteristics of the fuel affect the course of the pressure line and the rate-of-pressure rise.

Although the method may be less exact, a visual inspection of the cards (I.A.A. 8° B.T.C.) under a graduated celluloid mask shows the breakaway of the power-pressure line at 3° B.T.C. for fuel 2 and for fuels 1 and 3 within 1/2° of top center. The same method applied to the cards with injection at top center indicate ignition lags of 9° for fuel 2, 13° for fuel 3, and 15° for fuel 1.

The results of these strictly comparative tests showed that it would be possible to operate the engine with fuel 2 at greater injection advance angles than those to which the other fuels were limited by their knocking propensities. Accordingly the injection was advanced until finally a limit was reached when cylinder pressures became excessive although the combustion sound indicated that the knock had not increased to allowable intensity.

This change from the limitation of injection advance by allowable knock to limitation by allowable cylinder pressures is very desirable in laboratory tests and had occurred once before during supercharging tests with this same combustion chamber. The elimination of determining the injection advance by allowable knock intensities removes the possible variation in judgment of these knock intensities and allows a comparison of performance on the basis of maximum cylinder pressures. With rates-of-pressure rise comparable to those of fuel 2 the values obtained for maximum cylinder pressures with different types of indicating apparatus will be more nearly the same than with higher rates-of-pressure rise.

Tests were conducted to determine the optimum injection advance angle with fuel 2. These tests are not to be directly compared with any tests of the other fuels but show the performance that is possible beyond the range of the other fuels. Figure 4 shows the results of a constant-fuel-quantity run with variable-advance angle and Figure 5 shows the results of a run in which the b.m.e.p. was held constant by reducing the fuel quantity as the injection was advanced. Recollecting that the performance of all three fuels was the same at 8° injection advance it can be seen that the additional range of fuel 2 allows an increase of 10 per cent in power with the same fuel consumption or a reduction of 15 per cent in fuel consumption with the same power as the other fuels.

Figures 6 and 7 are curves of the same nature and were obtained by cross-plotting a number of runs. The significant feature of these four figures is that the optimum advance angle for fuel 2 is 14° B.T.C. for the test speed of 1,500 r.p.m. The curves also show that this value is not critical but may be exceeded by 6° without impairing performance, without exceeding permissible cylinder pressures, and without encountering a destructive knock.

DISCUSSION OF RESULTS

A review of the results of the comparative tests makes it apparent that the performance tests alone can not be depended upon to show any great difference in these commercial fuels for high-speed, compression-ignition, fuel-injection engines. Heat dissipation does not show any difference when the tests are on a comparative basis. Exhaust-gas analysis will give reliable indications as to the effectiveness of the distribution of the fuels and the completeness of their combustion but the two can not be separated.

A comparison of the results in a combustion chamber with high velocity air flow with those in a quiescent combustion chamber shows that the combustion process with air flow is relatively fixed and that the fuel has little effect on rates of combustion or rates of pressure rise. In the quiescent combustion chamber, however, the fuel does have a considerable effect on the combustion process as evidenced by the difference in rates of combustion and rates of pressure rise. As these combustion chambers are almost the extremes of the types with and without effective air flow, it seems that the quiescent combustion chamber is much better suited to fuel tests because the combustion chambers with air flow are relatively insensitive to changes in fuels.

Personal opinion

Because the analysis of indicator cards for rates of combustion requires more time than can be afforded by most laboratories for the sole purpose of rating fuels, it is desirable to have some other means of judging the relative merits of fuels. The miss-to-knock range of injection advance angle seems to satisfy the conditions for such a test of current fuels. The requirement of judgment of equal knock intensities should present no difficulties to an experienced laboratory engine operator when using fuels which

Heats are not important time secondary

actually do

limit the injection advance by knocking.

Using this knock-to-miss range of injection advance angle in the combustion chamber with air flow, fuel 2 is rated better than fuels 3 and 1, which are nearly alike, and the same ranking is obtained from the rates of combustion and rates of pressure rise. In the quiescent combustion chamber the rating is the same but instead of a miss-to-knock range for fuel 2 the advance limit was determined by the allowable cylinder pressure rather than the allowable knock so that the term "knock" is not applicable in this case.

The most suitable term for describing this range of injection advance angle is "the consistent operating range." As far as the present tests are concerned this consistent-operating-range value will rate the fuels as to desirability for a particular engine as well as much more complicated tests. This consistent-operating-range test may be made at a fuel quantity between half and full load but the fuel quantity should be the same for all fuels included in the comparative tests and the test speed must be held constant throughout all the tests.

The results of these tests show that in an engine with a quiescent combustion chamber a quick determination of the optimum injection advance angle may be made by advancing the injection at constant speed and at a constant fuel quantity between three-quarters and full load. If the engine-operating conditions are suited to the fuel it will be possible, without knocking or excessive pressure, to reach an advance angle beyond which there will be no increase in power. If knocking or excessive pressures occur while the power is still increasing during this advance of injection it is evident that either the engine-operating conditions or the fuel should be changed.

When the engine-operating conditions and the fuel are mutually suitable a more exact determination of the optimum advance angle may be made by advancing the injection of the fuel at constant load and speed until no further reduction of the fuel quantity is necessary to maintain the constant loading and a minimum specific fuel consumption has been reached. In these tests the injection advance angle at which the minimum specific fuel consumption is reached coincides with the injection advance angle at which maximum power is obtained.

CONCLUSIONS

These tests indicate that the results of tests in an engine with a quiescent combustion chamber are of more value in testing present fuels than are the results of tests in an engine with a high velocity of air flow in the combustion chamber. In general results with the two types of combustion chambers will be in agreement with each other.

Introduction

For either type of combustion chamber a comparative rating of the fuels may be obtained by noting the consistent operating range of the injection advance angle. This range is directly dependent upon the ignitibility of the fuel but involves no question of the method of measuring ignition lag.

Very indefinite see paragraph [illegible] discussion.

A fuel that will allow injection to be advanced beyond the optimum injection advance angle without encountering excessive knock or excessive cylinder pressures is a satisfactory fuel for that particular engine and its operating conditions.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 16, 1932.

BIBLIOGRAPHY

This bibliography includes only recent publications of results of engine tests. Collateral references to earlier work and to tests other than engine tests will be found in the publications listed.

Boerlage, G. D., and Broeze, J. J.: Ignition Quality of Fuels in Compression-Ignition Engines. Engineering, Nov. 13, 1931 pp. 603-06; Dec. 4, 1931 pp. 687-89; Dec. 18, 1931 pp. 755-56.

Butler, W. H.: Fuels for Automotive Diesel Engines. Paper presented at Meeting of Soc. of Auto. Eng. at White Sulphur Springs, W. Va., June 14 - 19, 1931.

LeMesurier, L. J., and Stansfield, R.: Fuel Testing in Slow and High Speed Diesel Engines. Journal Inst. Pet. Tech., July, 1931, page 387.

Pope, A. W., jr., and Murdock, J. A.: Compression-Ignition Characteristics of Fuels for Injection Engines. Paper presented at the Annual Meeting of the Soc. of Auto. Eng. in Detroit, Mich., Jan. 25 - 29, 1932.

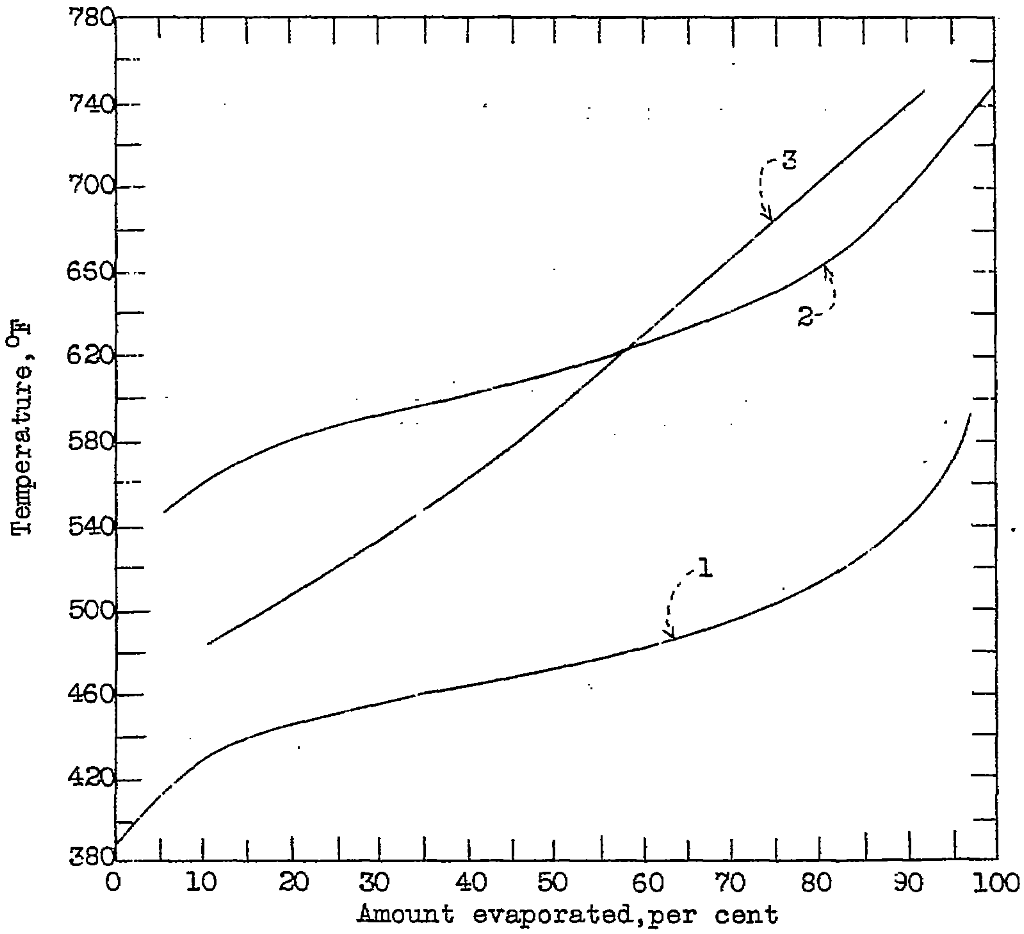

Fig.1 Atmospheric distillation curves for fuels 1, 2 and 3

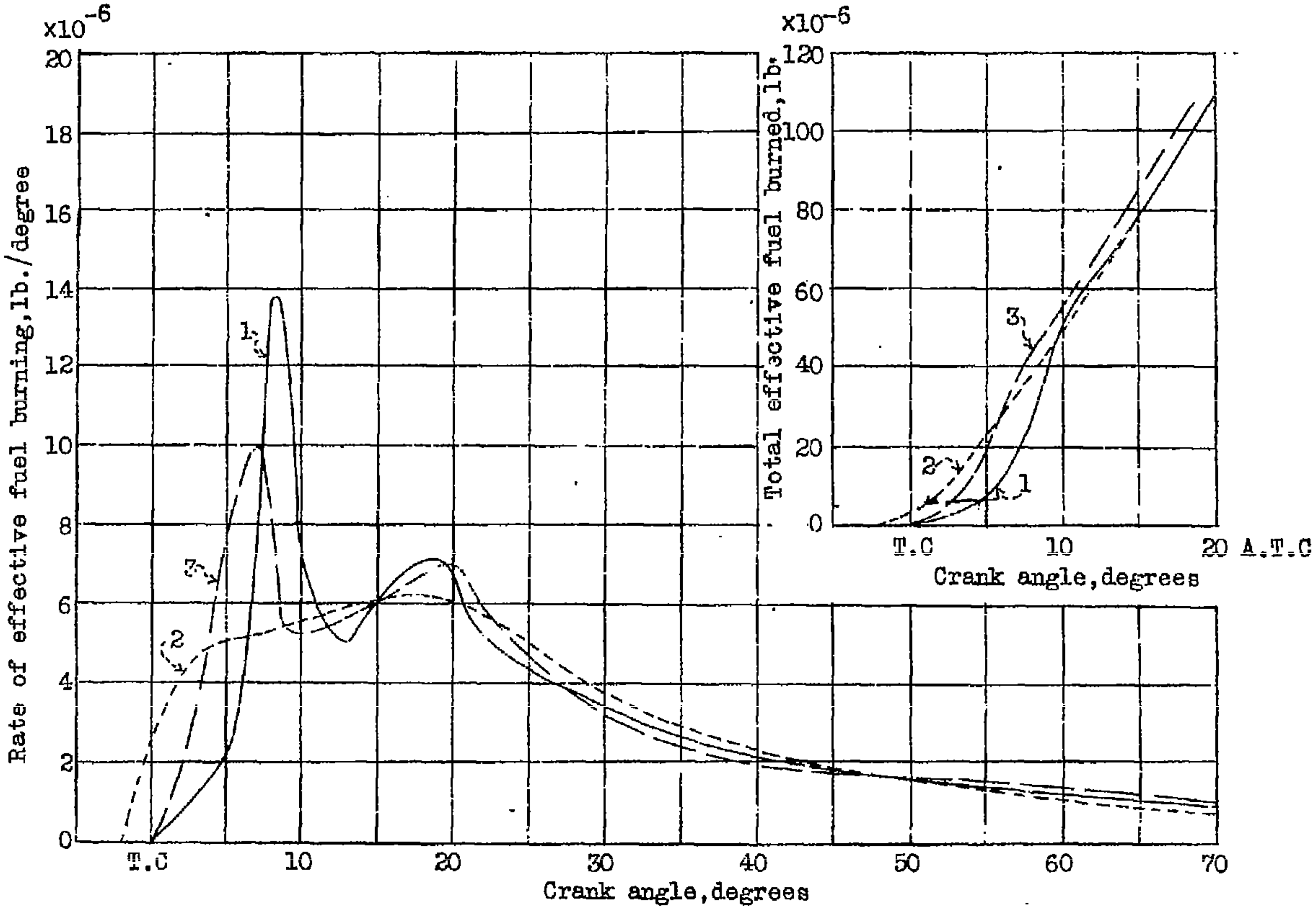

Fig.2 Analysis of indicator cards with injection at 8° B.T.C. in quiescent combustion chamber

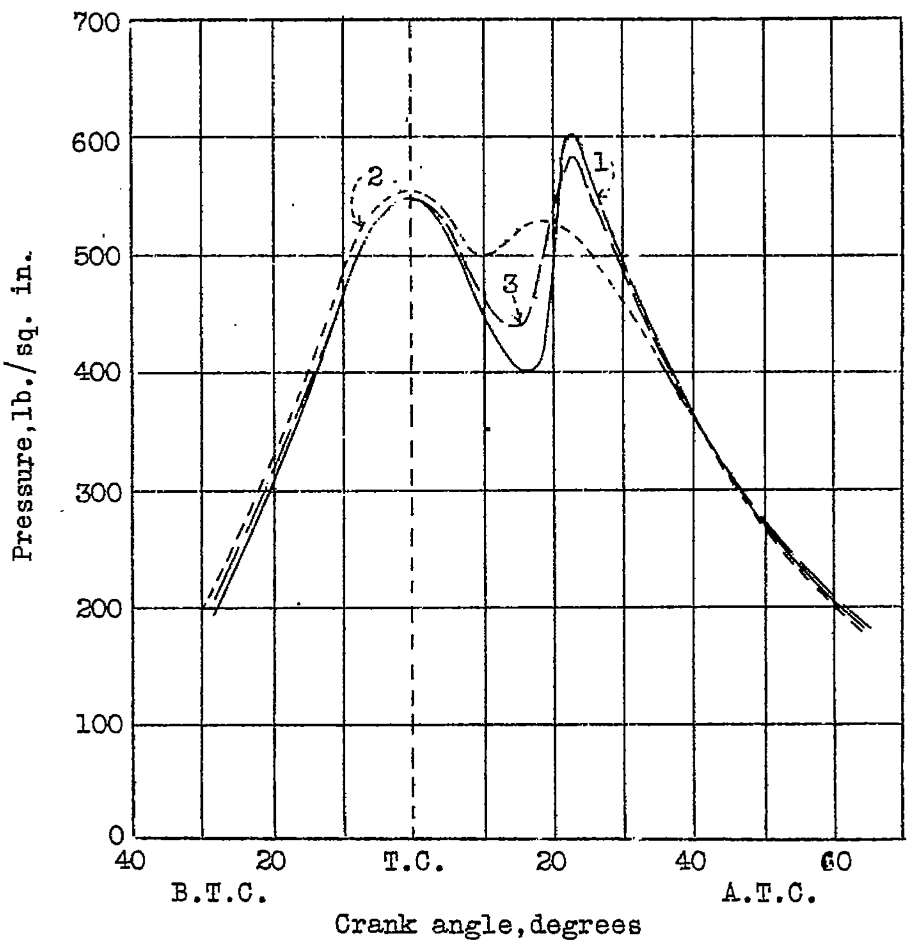

Fig.3 Pressure-time cards, with injection at T.C.

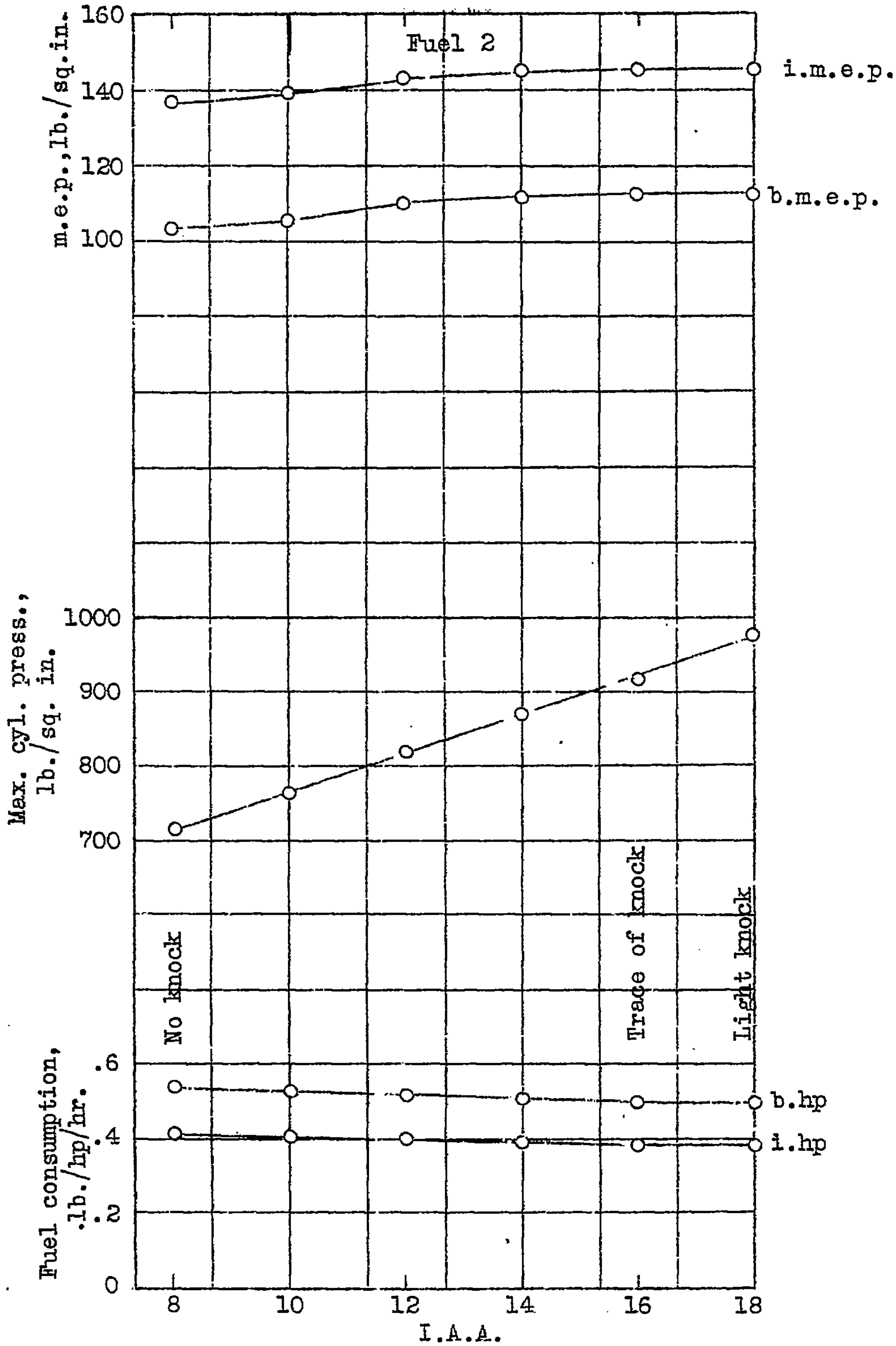

Fig.4 Effect of I.A.A. on engine performance,(full load 1500 r.p.m.)

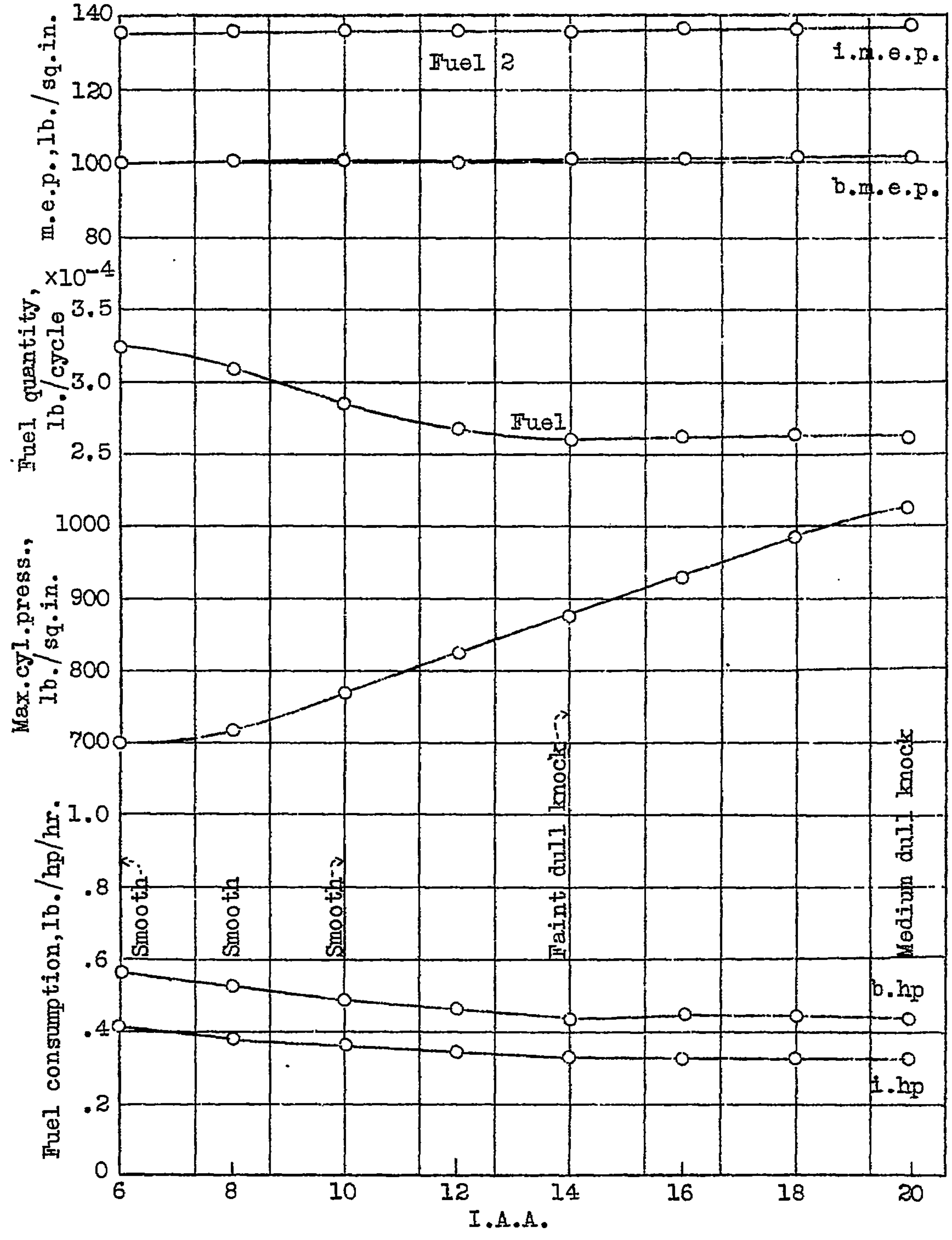

Fig.5 Effect of I.A.A. on engine perfoxmance,(constant m.e.p.).

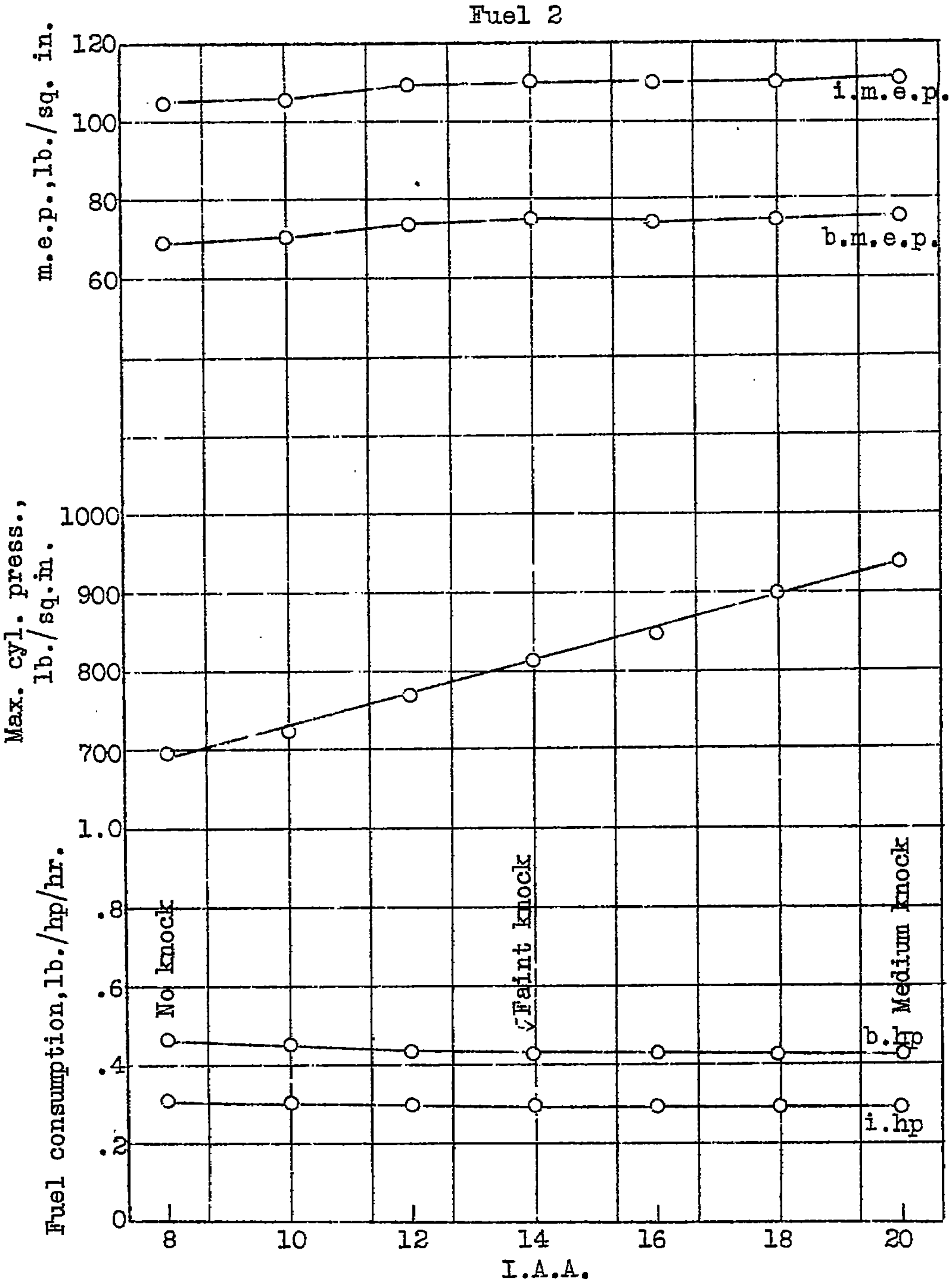

Fig.6 Effect of I.A.A. on engine performance.

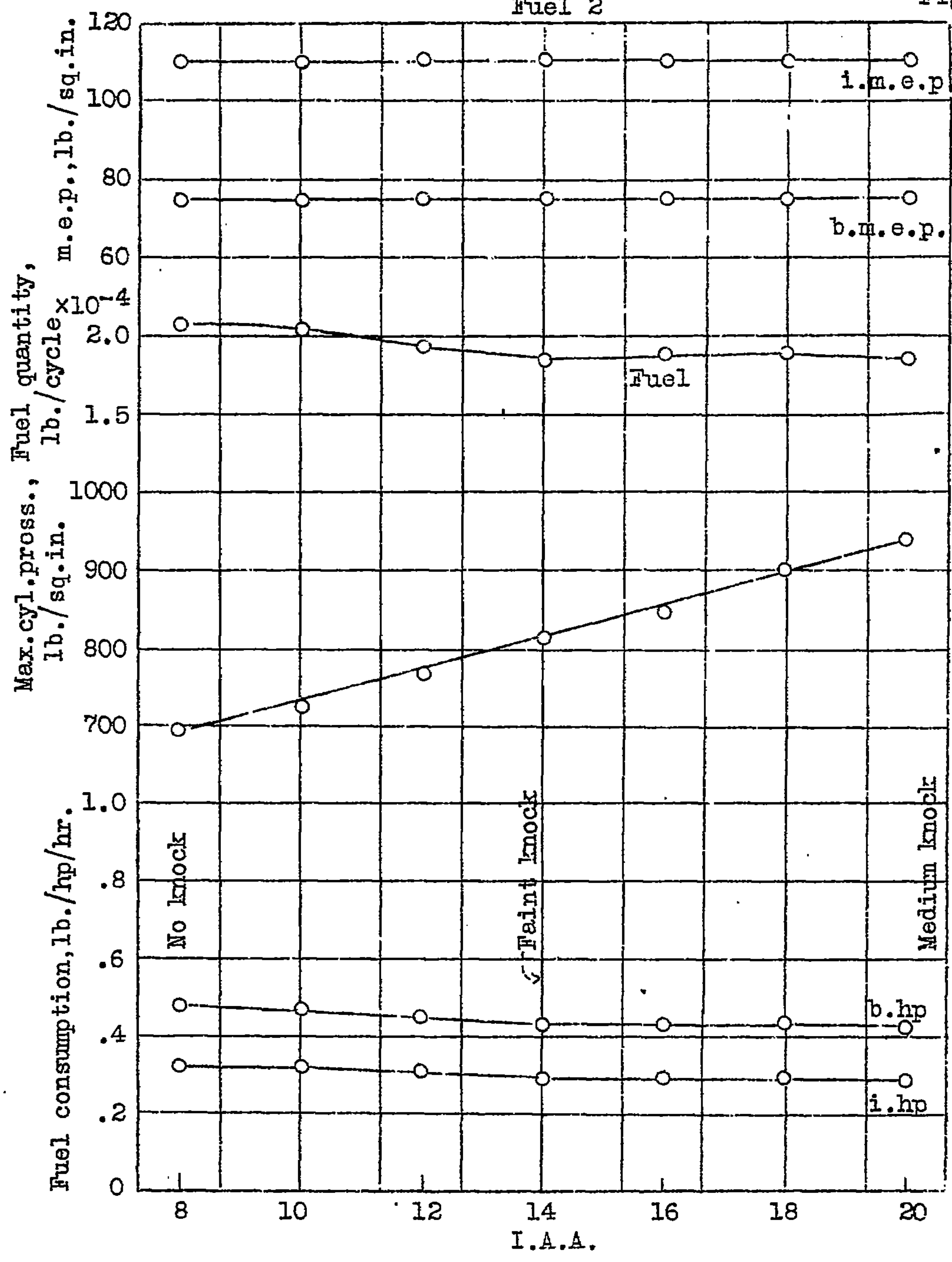

Fig.7 Effect of I.A.A. on engine performance.